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Technical Lesson 37

THE DEVELOPMENT OF THE SUPER-HETERODYNE

In previous lessons you learned that the regenerative circuit is capable of greatly amplifying the received signal impulses. A regenerative circuit can also be made to operate on what is known as the "autodyne" principle of reception, and since regeneration signifies one operating condition and autodyne another operating condition it is well to explain how these two different principles of reception can be made to function with the same identical circuit.

In the strict use of the term "autodyne" it is meant to convey the idea that the tube is caused to oscillate and, in the regenerative circuit, when the feed-back coil (also called the tickler coil) is closely coupled to the grid circuit, oscillation can be recognized by a distinct "plop" in the headphone as the tube goes into oscillation. When the circuit is in this condition it is said to be operating on the autodyne principle and is then adapted to receive continuous wave (C.W.) signals.

The term "regeneration" relates to the operation of the circuit when, by the proper regulation of the feed-back coil, the relation between the feed-back coil and the grid coil is such that the tube is NOT OSCILLATING but is feeding back energy to the grid circuit by means of the tickler coil to replace that which has been absorbed by losses in the circuit.

With the circuit operating in this condition modulated continuous wave signals may be received but not continuous wave signals. In both instances the feed-back action of the tube supplies energy to compensate for losses in the detector circuit, thereby improving selectivity and obtaining great amplification.

We now come to a principle used to obtain far greater amplification together with extreme selectivity and sensitivity and, while there is a similarity in some parts of the circuit of the methods just described, it will be seen that improvements are incorporated to obtain the desired results. This principle is embodied in the super-heterodyne receiver.

Two methods of amplification have been made known to you; the first method amplifies the incoming signal at radio frequencies and the second amplifies the rectified or detected signal at audio frequencies.

Radio frequency amplification is used before the detector tube circuit to amplify very weak signals that would not otherwise actuate the grid of the detector tube. Radio frequency amplification is very useful to strengthen a weak impulse and one of its greatest advantages is found when long distant reception is desired.

Audio frequency amplification finds its use in amplifying the radio signal after it has been rectified by the detector, thus building up the signal to a strength where it will satisfactorily operate a loud speaker. This is generally accomplished with two or three stages of audio frequency amplification. More than this is not generally successful due to tube noises which destroy the quality of the signal thus amplified.

Radio frequency amplification was employed quite satisfactorily at frequencies above 500,000 (equivalent to 600 meters). It was soon found, however, that on wavelengths below 600 meters, the amplification of the signal at the incoming high frequency presented many difficulties, and the lower the wavelength, the higher became the frequency, with increasing troubles in the control of such high frequency because the higher the frequency used, the more difficult it is to confine it to the circuits in which it is intended to function. As a great deal of radio signaling was carried on at low wavelengths, it was apparent that there was a great need for an amplifier that would satisfactorily operate at these high frequencies.

At high frequencies the capacity effects become very detrimental to the proper handling of these minute high frequency impulses, such as the capacity effect between the wires used to connect the circuits. In many cases the capacity between adjacent wires is not objectionable when working at low frequencies (high wavelength). On the other hand, these same capacity effects act as short circuits to high frequency (low wavelength) signals.

The vacuum tubes themselves presented the greatest capacity difficulties. Many experiments were conducted with all the vacuum tubes available when the three element tube was first used in radio frequency amplifiers. It was soon evident, however, because of their high grid to plate capacity, high filament to grid and filament to plate capacities, that satisfactory amplification at even moderately high frequencies, such as 500,000 cycles (600 meters) per second or higher, could not be obtained. These capacities were found to act as short circuit paths for high frequency which amounted to short circuiting the radio frequency amplifiers.

It is therefore realized that the difficulties of amplification at radio frequency were real and since it was difficult to reduce the capacity of the tubes which was so detrimental at high frequencies, the problem finally resolved itself into the origination of a scheme whereby the amplifier could operate at some frequency which would not present the difficulties just mentioned.

At a frequency of 1,000,000 cycles, which is equivalent to 300 meters, a capacity of 8 micro-microfarads is equivalent to approximately 100,000 ohms reactance, while at a frequency of 50,000 cycles or a 6,000 meter wavelength, the same capacity would present a reactance of approximately 2,000,000 ohms. At 6,000 meters, or a frequency of 50,000 cycles, the short circuiting effect of high frequency is not evident. Therefore,

with an amplifier designed to operate at 50,000 cycles, amplification can be carried out satisfactorily.

It was on this principle that Major Armstrong worked, thus developing the super-heterodyne.

The super-heterodyne circuit consists of the following parts:

- (a) A loop which is used as the aerial to pick up radio signal impulses.
- (b) An oscillator.
- (c) A frequency changing tube called the first detector.
- (d) A multi-stage intermediate frequency amplifier unit.
- (e) The second detector.
- (f) An audio frequency amplifying unit.

A super-heterodyne circuit with the various units marked is shown in Figure 1.

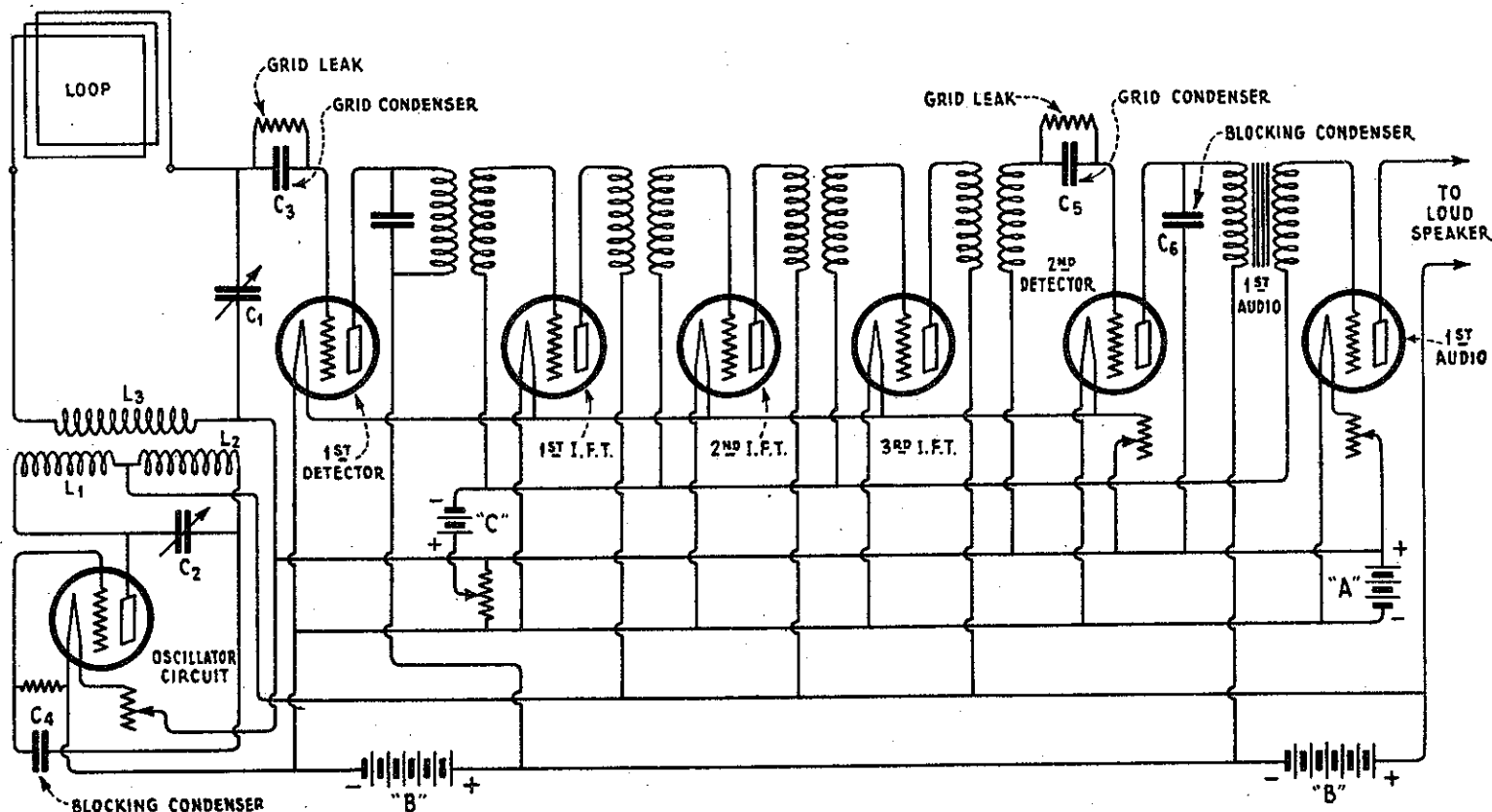


Figure 1

In the various forms of receiving circuits you have studied, any signal picked up by the tuning inductance coils is amplified as well as the signal to which the set is tuned. In the super-heterodyne, however, this undesirable condition is practically eliminated by adjusting the frequency of the local oscillator which combines with the frequency of the incoming signal to a point where the beat frequency which is thus produced will be above audibility. In many sets this is 50,000 cycles.

In other words, the wavelength was converted from a low wavelength to one of high wavelength which was exactly the condition desired in order that radio frequency amplification could be satisfactorily carried out.

Let us assume that the incoming frequency oscillation picked up when tuning the loop by means of a condenser and impressed on the grid of the first detector or frequency changer is 1,000,000 cycles per second, which would be the signal from a station transmitting on a wavelength of 300 meters. The oscillator is now adjusted by means of the variable condenser C_2 to a frequency of 1,050,000 cycles per second; this is also impressed on the grid of the first detector through the pick-up coil L_3 .

We now have two different frequencies being impressed on a common circuit; that is impressed upon the grid of the first detector. When two different frequencies are thus impressed on a common circuit, they produce a third, or beat frequency, and the frequency of this beat will be the difference between the two impressed frequencies. Since the incoming frequency was 1,000,000 cycles and the oscillator frequency was 1,050,000 cycles, the difference between these two frequencies will be 50,000 cycles. We now have a frequency which is lower than the incoming frequency of 1,000,000 cycles to work with, namely, 50,000 cycles, and consequently higher in wavelength, being equivalent to 6,000 meters. This beat frequency is called the intermediate frequency, and is passed to the first intermediate frequency transformer (abbreviated I.F.T.), where it is amplified and then passed on to the second and third intermediate transformers. (Amplification can be carried on for more than two stages if desired). After passing through the intermediate frequency amplifiers, it is impressed on the grid of the second detector.

The function of the second detector is the same as that of the detector in any radio receiver, which is to change the high frequency alternating wave to a pulsating direct current. This of course, as you know, is carried out to change the alternating current into a form that will actuate the diaphragm of the telephone receivers.

Generally this rectified current is passed through two stages of audio amplification which steps it up to a value which will satisfactorily operate a loud speaker.

THE LOOP AND FIRST DETECTOR CIRCUIT

The fundamental principle upon which the super-heterodyne circuit is founded is shown by Figures 2 and 3. Figure 2 shows an aerial in the form of a loop, a detector, and a variable condenser.

If the loop and condenser are tuned to resonance at some particular frequency, radio signals of that frequency will then be received and impressed on the grid of the tube. Let us leave this circuit for a moment and work with the circuit of Figure 3 which shows a simple oscillator.

This consists of an inductance coil in the grid circuit and one in the plate circuit. These coils are so arranged that energy from the plate circuit coil will be inductively supplied to the grid circuit coil.

A variable condenser placed between the grid and plate sides of the two coils makes possible the tuning of this coil, and also enables one to tune the system so that it will oscillate at a frequency which will permit the circuit to be used for practical reception.

Depending upon the inductance of the coils and the capacity of the condenser, the frequency can be made anything within the range of the value of these units.

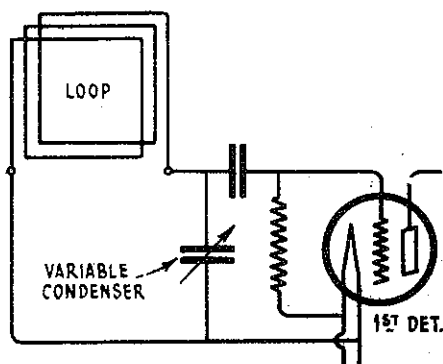


Figure 2

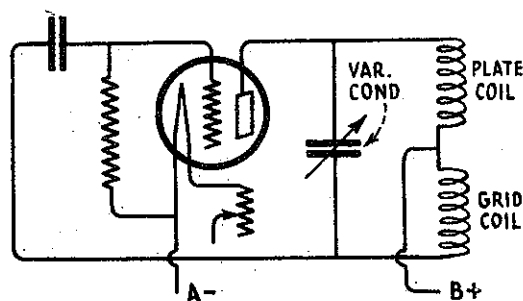


Figure 3

With such a system capable of producing radio frequency oscillations, we will couple it to the circuit of Figure 1 by means of a small pick-up coil shown by L_3 . We now have three coils in the coupled oscillator, L_1 in the plate circuit, L_2 in the grid circuit and L_3 in the grid circuit of the frequency changer or first detector. We also have two variable condensers; C_1 in the first detector circuit to tune the loop, and C_2 in the oscillator circuit. These are the only tuning controls necessary in the super-heterodyne.

Now by adjusting C_1 , we may have the frequency of any desired signal in the loop circuit; and the oscillator circuit may be made to produce any desired frequency independent of external signals or forces. With these two circuits coupled, the frequency produced by the oscillator is impressed on the loop circuit frequency and these two frequencies mixing or combining produce on the grid of the first detector a third frequency, commonly called the beat or intermediate frequency, which is lower in frequency than the incoming signal frequency but higher in wavelength.

THE INTERMEDIATE FREQUENCY TRANSFORMERS

Now that we have the incoming wave converted to a higher wavelength, particular attention must be directed to the intermediate frequency transformers whose function it is to amplify this intermediate frequency through several successive stages. These transformers may be either the air or iron core type. Iron dust is generally used in making up

the iron core type, and is frequently employed in all the intermediate stages with the exception of the first or last stages.

Either the first or last intermediate stage is of the air core type and should be tuned to pass only the inaudible beat frequency. The intermediate transformers are therefore designed to amplify the frequency desired with all efficiency possible by so selecting the inductance values of each transformer that they will pass this particular frequency with the greatest possible transfer of power. These transformers are tuned rather broadly to the chosen intermediate frequency to be used so that each successive stage will increase the signal passed to it from the preceding stage and also at the same time act as a filter to prevent all other undesirable signals reaching the second detector which might have passed the first detector.

It is the enormous amplification attained and the ability of the intermediate frequency transformers to filter out all but the desired frequency that gives to the super-heterodyne that distinctiveness for which it is noted, namely, extreme sensitivity and selectivity.

THE DETECTOR AND AUDIO TRANSFORMERS

This portion of the super-heterodyne is, and functions the same as, the detector and audio amplifier in any other receiver.

The audio amplifier may be any of the regularly used types. The distinct difference in the super-heterodyne is in the use of the oscillator and the intermediate transformer units. The first super-heterodyne as originally constructed by Major Armstrong, was a nine tube set necessitating the use of storage batteries of large capacity and was not a set that could be economically maintained by the average person. With the introduction of dry cell operated vacuum tubes and storage battery tubes of low current consumption, the problem of producing a super-heterodyne within the reach of anyone was possible.

After exhaustive experiments a means was evolved whereby the first detector was made to function both as the oscillator and as first detector, thus eliminating one tube. This was not a simple solution but one which required considerable research and time. Armstrong finally developed a simple and effective arrangement which solved the problem completely, namely, that of connecting two tuned circuits to the oscillator; one a simple circuit which could be tuned to the frequency of the incoming signal, and the other a regenerative circuit which could be adjusted to oscillate at some particular frequency, the second harmonic of which, beating with the incoming signal frequency, would produce the frequency desired for intermediate amplification. A fundamental circuit of this idea of the two tuned circuits is shown in Figure 4.

Assuming that the frequency of the received signal is 600,000 cycles and the amplifier tuned for 50,000 cycles, then the heterodyning frequency must be 550,000 or 650,000 cycles. When these conditions are obtained, the tuning of the loop condenser C_1 of Figure 4 to the desired radio

impulse will affect circuit of C_2 , thus requiring a change in the setting of C_2 . In a similar manner the tuning of C_2 will react upon the loop circuit. To eliminate this difficulty the second harmonic of the oscillator frequency is used for heterodyning.

By reason of certain assymetrical characteristics of vacuum tubes acting as oscillators, not only a fundamental frequency is secured but a series of other frequencies also are produced called upper harmonics, whose frequencies will be exact multiples of the fundamental. If, for example, the oscillator is tuned to 275,000 cycles per second, we will obtain in addition to this fundamental frequency of 275,000 the following frequencies: 550,000 cycles; 825,000 cycles; 1,100,000 cycles, and so on. These frequencies are called the second, third and fourth harmonics, respectively, and correspond to two, three and four times the fundamental frequency of 275,000 cycles.

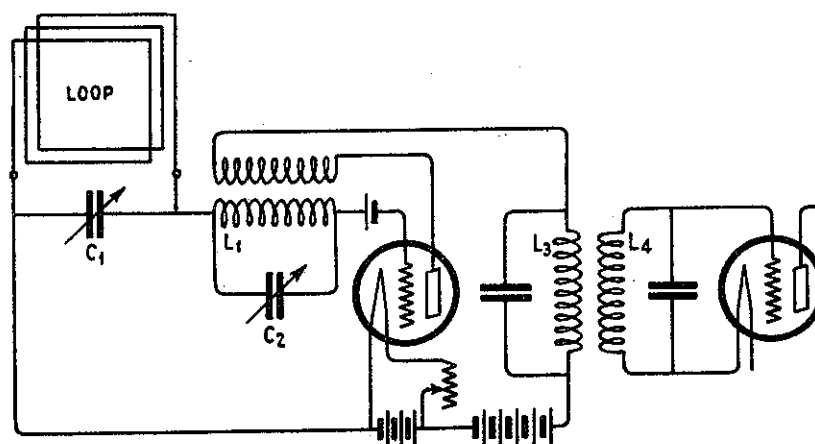


Figure 4

If the second harmonic is used the oscillator is adjusted at a fundamental frequency of 275,000 or 325,000 cycles which produces a second harmonic of 550,000 or 650,000 cycles. Since, in this method, the loop and oscillator circuits are tuned to frequencies which so widely differ, the tuning of one has no harmful effect upon the other. Therefore, the use of one tube to act as both oscillator and detector was solved.

A reduction of the number of tubes in the Armstrong super-heterodyne was desired. This was brought about by a method of reflexing, thus eliminating another tube by making the radio frequency amplifier function both as a radio frequency and an intermediate amplifier.

With a view to the servicing of several of the commercial types of receivers, full and complete instruction will immediately follow; the first being a full description of a Radiola Super-heterodyne, operating on the second harmonic principle, with full information pertaining to accessories needed, together with step by step procedure for testing these receivers to correct possible troubles.

EXAMINATION - LESSON 37

1. What is an advantage of radio frequency amplification?
2. Can radio frequency be utilized below 600 meters as successfully as at higher wavelengths?
3. What are the principle parts of a super-heterodyne circuit?
4. Explain briefly in your own words, the function of the super-heterodyne.
5. What is the function of the intermediate transformers?
6. What is the purpose of the first detector?
7. Do any of the intermediate frequency transformers have an iron core?
8. Is the wavelength of the incoming signal converted to a higher or lower wavelength by the super-heterodyne circuit?
9. What is the function of the second detector?
10. What is the function of the oscillator in the super-heterodyne circuit?